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Energy conservation options for cooking with biomass in Ghana

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Abstract

Cooking is the main energy consuming activity in Ghana. This is mainly due to a generally low material standard of living, but also because the cooking process itself is energy inefficient. The fuel for cooking in Ghana is mainly biomass either in the form of wood, agricultural residues or charcoal. An energy chain for the cooking process is established and the possible conservation options are surveyed in kitchen performance tests in Abodom in the tropical zone of Ghana. The energy consumption for the food preparation has been measured and energy saving options have been determined for some parts of the energy chain. The results show that the possible options for energy conservation through the entire energy chain of the present technology are at least of the same magnitude as that involved in just switching to a more efficient biomass stove. The heat loss is largest while simmering when the boiling point has been reached. Most cooks tend to continue using a high heat supply even though it is not necessary. This process is often carried out without lid on the pot even though the use of lid will reduce the energy loss considerably. It is also concluded that the average fuelwood consumption in Abodom per household (tropical zone) only is 20% higher than the per family fuelwood consumption in the northern part of Ghana (Guinea Savanna). A larger difference in fuelwood consumption per household is normally assumed between households in tropical zones and in savanna zones.

Firewood consumption in rural areas in Ghana

Around 70% of total energy consumption in Ghana is from biomass[1]. A survey carried out by the Ministry of Energy, 1991 on energy consumption patterns in 6 communities in the northern part of Ghana indicates that around 90% of the energy used in the households is biomass. The figures vary between an average biomass consumption in rural villages such as Kongo of 1.7 tonnes/household/year and 1.4 tonnes/household/year in Tongo, among those households which use biomass as the main energy source. These villages are not connected to the electricity grid.

There are no detailed data of biomass consumption for cooking throughout the country. This also applies to data on efficiency of the cooking process. There are 1.9 million households in

[1] Hagan and Addo, 1994: Determination of Domestic Energy Consumption patterns and their impact on the environment in Ghana.

Ghana and the total fuelwood consumption is 11 million tonnes[2] If 80% of the biomass is used for cooking and 90% of the population rely on biomass, the national average should be around 5 tonnes of biomass per household per year of those families which use biomass as the main energy source. But as indicated above the annual average is only around 1.5 tonnes per household in the villages in the northern part of Ghana. When only 1.5 tonnes per household are used in the northern part of Ghana, the household consumption should be much higher than 5 tonnes per household in the tropical zone to reach a national average of 5 tonnes per household. For completion of the questionairre survey in the tropical zone it was assumed that a high woodfuel consumption per family in the tropical zone would also mean large saving options.

Large differences in fuelwood consumption may be ascribed to availability of fuel. A variation of 0.5 to 2.9 tonnes per person per year is found by Scurlock and Hall, 1990[3]. This difference is also shown by Dewees (1989)[4]. He argues that the per capita woodfuel consumption in a dry country like Afghanistan is only 20% of woodfuel consumption per capita in a forested country like Papua New Guinea.

The major advantage of using fuelwood for cooking in developing countries is that it is collected free of cost. Scarcity of fuel, however, increases the time spent on gathering woodfuel. This reduces the possibility for women to undertake economic activities. Furthermore, the health impacts due to exposure to smoke are one of the largest health problems in the developing countries.

There are many possibilities through the cooking process to reduce the consumption of biomass. Using tree species with good burning properties, using dry wood instead of recently cut wood are some of the options which, if they were taken advantage of, could improve the woodfuel situation and the health situation in the countries remarkably. Some are very aware of this, and large variations of biomass consumption occur between cooks. Besides saving woodfuel the improved stoves may also reduce smokes.

Saved wood in the food preparation process

The energy chain for the food preparation process

Establishment of an energy chain for the food preparation process is a method for estimating the conservation options at each step throughout the whole cooking process. In the following the different parts of the energy chain of the food preparation process are described. The energy chain is shown in Figure 1. Biomass is used as the energy source, the stove used for transferring energy from the biomass to the pot and the pot (and lid) is used as vessel for the meal. Firing control and cooking performances are included as the major variables which to some extent are controllable for the cook. Khummongkol (1986)[5]. describes the different efficiencies:

[2] Wuddah-Martey, 1994: Reducing charcoal consumption in Ghana. A case for the Ahibenso improved coalpot.
[3] Scurlock and Hall, 1990: The contribution of Biomass to the Global Energy Use.
[4] Dewees, 1989: The Woodfuel Crisis Reconsidered: Observation on the Dynamics of Abundance and Scarcity.
[5] Khummongkol, 1986: Review of Standard Methods of Testing Stoves Efficiency.

1. **combustion efficiency** = heat generated by combustion divided by energy potential in fuel,
2. **efficiency of heat transfer** = gross heat input to the pot divided by the total heat generated,
3. **pot efficiency** = net heat input to the pot divided by gross heat input to the pot, and
4. **control efficiency** = heat absorbed by the food divided by net heat input to the pot.
5. **overall efficiency** = heat absorbed by food divided by energy potential in the wood.

The different efficiency measures indicate that there are many ways in which the efficiency of the food preparation process can be described. The choice depends on which kind of efficiency is under study. In the present study the aim is to identify the total efficiency of the whole food preparation process. Available data are limited, especially on efficiency tests in real life conditions.

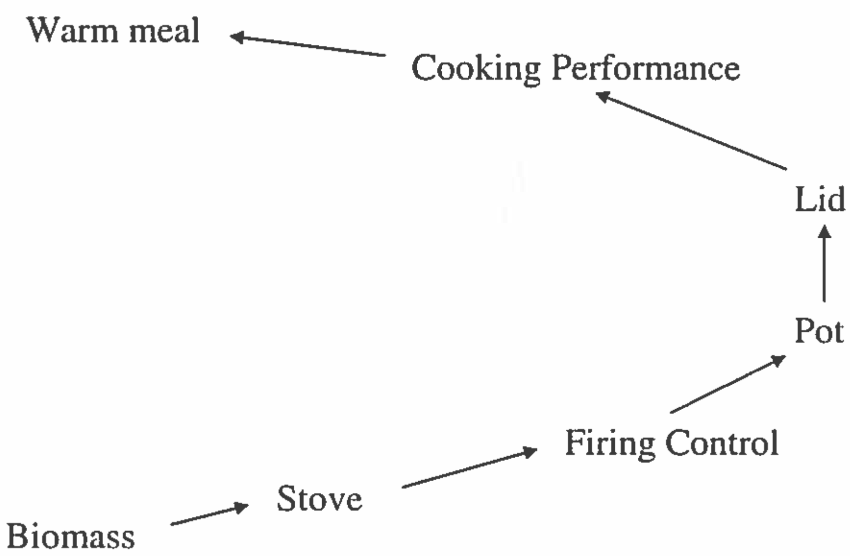

Figure 1 The energy chain for preparing food. Preparation of ingredients is not included.

Biomass

The energy chain starts by biomass. Different kinds of biomass can be used, but for cooking in Abodom mainly fuelwood is used. As Abodom is situated in the tropical zone fuelwood is abundant. The energy content in the wood vary depending on the wood and the season (water content), but the main difference among tree species for cooking is the difference in smoke production. Some species are specifically mentioned as good cooking fuels.

Stoves

The three-stone stoves are very popular. They have no cost and in areas where wood is freely collected the use of the three-stone stove is free. The stove is easy to make, use and handle. The safety is also relatively high as children can see and feel the fire. The firing control is easy because it is possible to use long logs which are pushed into the flames while they are burning. When heat is no longer desired the logs are easily pulled out of the fire and the burning stops. Also different kinds of agricultural residues, such as millet straw and grasses are used with three-stone stoves where firewood is limited. Here the firing control is more complicated.

The improved stoves try to eliminate some of the bad habits which reduce energy efficiency in the food preparation process using three-stone stoves. An improved stove will typically require the fuel to be fired in a specific way. The losses will be reduced if this is done correctly. However, if an improved stove is used wrongly the energy losses may be even larger than for a three-stone stove.

Three-stone stoves are the traditional stoves in Ghana. The efficiency of the stoves depends on the cook's firing control skills. The efficiency therefore vary tremendously. Compared to an improved metal stove it is relatively difficult to obtain the optimal energy output and difficult to obtain the optimal distance to the pot. There are several improved stoves which are based on the three-stone stove, for instance "stones" may be built with clay and built with a clay-wall between two of the "stones". This reduces the loss of conducted heat, by leading the heat up around the pot and reduces exposure to wind. In Ministry of Energy, 1991[6] the main explanation for only using 50% of biomass per household in Kongo compared to Tongo, is among other things the use of three-stone stoves in Kongo, and clay stoves in Tongo.

It is, however, difficult to determine the efficiency of the three-stone stoves even though a common framework is established. Often it is claimed that the three-stone stoves have a stove efficiency between 6 and 8%[7]. However, in laboratory tests it has been claimed to be 23% with 25% moisture content and the pot placed at a height of 7.5 cm above the base of the fire[8]. But many things change the stove efficiency remarkably when cooking is carried out in real life. For instance, cooking outside the house instead of inside changes the stove efficiency.

In the following the stove efficiency is estimated to be 21% for an outdoor three-stone stove with use of biomass with 25% moisture content, optimal firing control, optimal distance between pot and stove, and use of lids. This corresponds to a 10% reduction in the theoretical stove efficiency due to the outdoor placing.

Firing Control

The stove efficiency is dependent on the heat transmission and the firing control. Firing control seeks to obtain the optimal power output during the cooking process. While heating up, high power output is an advantage, but lower power is needed while cooking. Cutting of wood into smaller pieces has been found save 22% compared to the use of long wood pieces, using existing firewood without adding new wood logs for simmering save 57% and putting the fire out after use saves 18%[9].

It is difficult to separate the stove and the firing control in the energy chain, because the firing control is one part of the chain which the stove developer improves upon. If we compare the

[6] Ministry of Energy, Ghana, 1991: A Report on Energy Use Patterns in Bolgatanga, Bawku East and Bawku West Districts of the Upper East Region of Northern Ghana.
[7] Baya-Vuma, 1989: 10 Years of Improved Stoves in the Sahel.
[8] Supra note 7.
[9] All three numbers are from Gitonga et al., 1994: Back to basics in the Kitchen.

three-stone stove with modern stoves like the electric and LPG stove, it is obvious that the power control at the modern stove is easier to use.

Pots and lids

For various stoves different problems arise for obtaining a high pot efficiency. For three-stone stoves, a plain bottom of the pot is generally not necessary. The three-stone stoves have an advantage when using different pots as the stones can be moved to obtain the most efficient distance between the fire and the pot. This optimal distance, however, differ during cooking depending on the heat demand. Furthermore, it is difficult to move the stones while cooking. Improved stoves are usually produced to fit precisely to certain pots, which is part of its higher stove efficiency. Therefore the use of different pots will reduce the efficiency. Another uncertainty is the use of proper pots and lids for the various types of cooking. Aluminium pots are generally most efficient for short-time cooking due to the lower thermal mass.

Cooking Performance

The use of lid could also be defined as a part of the cooking performance, but it has been separated in this case. Cooking performance include the pre-soaking of food, cutting the food into smaller pieces and using minimal amount of water in the cooking process. Pre-soaking food reduces energy consumption by 39%[10], cutting in smaller pieces reduces energy consumption with 35%[11], and the use of minimal amount of water reduces energy consumption by 20%[12]. The choice of a proper pot for the purpose, aluminium or clay, reduces the energy consumption up to 18%[13]. Furthermore, the choice of proper size of pot with regard to the amount of food to be prepared also reduces heat loss.

Results of questionnaire tests

In the following, the results from a questionnaire survey are presented. The survey was carried out in Abodom. This village was chosen because another survey had been carried out in the village and the existence of a health clinic where it was possible to stay made the choice relevant. Furthermore, it was "only" 100 km from Accra, which made necessary travels between the village and Accra possible. Only 10 questionnaires were conducted, which is not sufficient for secure statistical conclusions, but the information is helpful as an indication. The response of the questionnaire gives a preliminary picture of the cooking performance in the area. The survey was connected to a joint research project between Physics Department at The Technical University in Denmark and the Department of Physics at the University of Ghana.

The aim of the questionnaire was to illuminate traditions in the cooking process, habits, what was eaten, type of stove, type and amount of fuel and which types of meals are boiled with or without lid.

Preparation of questionnaire

Two sets of questionnaires were developed, the second one being an improvement of the first one. The interviews were carried out by use of a translator, even though some English was

[10] Gitonga et al., 1994: Back to basics in the Kitchen.
[11] Supra note 10.
[12] Nørgård, 1989: Low Electricity Appliances - Options for the Future.
[13] Supra note 10.

spoken in the village. The kitchen performance tests are very time consuming. It takes a day to make an interview.

Abodom

Abodom is a village with 10.000 inhabitants, situated 100 km North-west of Accra. The village was not electrified at the time when the tests were conducted, but electricity poles were being established. The village is dependent on agriculture, which means that most people work at farms or they have their own farm-lot. In this way they are able to fulfil their fuelwood demand at the farm from which the wood is carried home to the village after the working day. Carrying 10-15 kg of fuelwood is normal. In many cases this amount is not sufficient as they only work on the farm 2-3 days a week. This is especially a problem when food products also are to be carried home.

General information gathered from the questionnaire

Meals

All households consider themselves as farmers, which in most cases means that they have a kind of "home-garden" (a kind of agroforestry). They cultivate themselves most of the food they eat.

The women in the households cook, and they have learned to cook from their mothers. Food is prepared twice or three times a day (in 90% of the houses three meals are cooked). This means that not only a considerable amount of energy is used for preparing food during the day, but also a lot of time is spent. As a contrast, in Denmark only the dinner is cooked in most households. A lot of food is produced in the households for being sold at the markets, along the roads etc. during mornings, lunch and after darkness.

In the first interview session the cooks were asked what they normally eat at the different meals. For breakfast all eat warm meals, kenkey, banku and coco, which are corn-products and 60% eat ampesi (cooked vegetables). For lunch all eat ampesi and 60% eat kenkey. For dinner all eat fufu, which is pounded casava and plantain and 40% of the different meals are based on corn-products. In the second session of the interview the cooks were asked what they had prepared the last three days, which gave quite similar answers. Warm drinks are rarely prepared.

Habits.

Generally only one fireplace is used (80%). The soup is boiled first and then the vegetables. Afterwards the soup is reheated. All cooks use a lid when they cook the vegetables, but 70% do not use a lid for cooking the soup/stew. 70% say they try to reduce heat supply when the boiling point is achieved. Of those who cook beans 78% soak the beans before boiling. For 33% the cooking time is less than 1 hour.

All of them cook soup for more than one meal at a time. The uneaten part is reheated twice a day to conserve and to prepare for the next meal. 40% say they use the evenings´s soup the following morning.

Stoves

All the households involved in the questionnaire use a three-stone stove. The three-stone stoves are made of clay with lower clay walls between the stones. 30% use a coalpot (for charcoal) as backup when the cooking must be fast. The arguments for the choice of stove are for 50%

abundant supply of wood and for 30% traditions. 70% of the fireplaces are placed in a hut separate from the house. All mention smoke as problem while cooking and this is especially the case when the wood is wet in the rainy seasons. 60% answer that they think about wood saving and the rest does not.

Both aluminium pots and iron pots are used.

The fuel

All use woodfuel as the main fuel. 90% collect the wood at their own farms. They bring the wood home when they have been on the farm. It is primarily the women who collect the wood. Children help in 20% of the cases and in 10% the man helps. All households say there are problems in getting wood, especially in the rainy season. It has not been possible to estimate the number of kilograms they carry. It depends on the physical conditions of the individuals.

Kitchen performance test

In Table 1 energy consumption for eight of the households surveyed is shown. The total energy consumption does not vary much, and the same applies to the average power of the fire. The average power is determined by measuring the wood consumption from ignition of the fire to the pot is taken of and the fire stopped (ashes subtracted).

The energy consumption per person varies mainly as a result of different family sizes. The energy consumption is, however, not only a result of the family size as seen by comparing Abo3 and Abo6 and comparing Abo9 and Abo10. The highest consumption per person is in Abo2, Abo6 and Abo9 where the families are smallest. That the power of the fire is quite similar, indicates a control problem of the fire. In Table 2 figures for the use of stove and the lid are outlined. It shows that lid is generally not used very much, but the figures also vary. The total cooking time for Abo3 explains the low energy consumption. Abo3 was for preparing lunch. Finally by comparing the energy consumption from Abo2 with Abo7 and Abo8 the lower energy consumption per person in Abo7 and Abo8 stem from the use of lid.

	Persons (Person. equivalents)	Daily biomass consumption per household MJ	Daily biomass consumption per pers. eq. (MJ/pers-eq.)	Power kW
Abo2	3.4	52	15	6.7
Abo3	9.1	41	4.5	6.7
Abo4	6.1	61	9.9	7.5
Abo6	2.6	52	20	8.8
Abo7	4.2	43	10	6.3
Abo8	4.8	56	12	7.4
Abo9	2.6	69	27	7.0
Abo10	6.6	56	6.6	6.1

Table 1 Daily biomass consumption for eight households (rounded numbers). The energy consumption per person equivalent means that children only count by a factor of 0.5, women (older than 14) by 0.8 and men above 59: 0.8 person equivalents. The figures are for preparing different meals. Abo2, Abo4, Abo9 and Abo10 are directly comparable as they are for preparing fufu and palmnut soup.

	Lid (%)	Use of lid while boiling/simmering (%)	Use of Stove (%)	Cooking time of meal (hours:min)
Abo2	32	27	89	1:33
Abo3	26	68	76	0:39
Abo4	28	29	94	1:32
Abo6	29	21	99	1:08
Abo7	94	96	84	0:57
Abo8	100	100	92	1:20
Abo9	70	80	75	1:28
Abo10	50	25	82	1:03

Table 2 Different figures from selected meals from the kitchen performance test. The percentage of households using lid throughout the preparation is shown in the first column, and in the second column the percentage of cooking time with lid while boiling is outlined. The percentage of using the stove while the fire is burning is estimated in column three and the total cooking time is shown in column four.

The total cooking time varies from 1:03 to 1:33 hours. One may expect to find the explanation for this in the different sizes of the families, but apparently this is not the case. In Table 3 the cooking time for cassava and/or plantain is shown. Abo4 boils it for a longer time, which may be explained to some extent by the shorter heating time. But for Abo2 the boiling time is 9 minutes longer, even though the heating time is 2 minutes longer. The differences should not be so much for boiling the cassava, which is similar to boiling potatoes in Denmark. The total cooking time 30% higher for Abo2 than Abo10.

	Abo2	Abo4	Abo9	Abo10
Heating	0:16	0:09	0:15	0:14
Boiling	0:25	0:28	0:19	0:16
Total	0:41	0:37	0:34	0:30

Table 3. Cooking time for heating and boiling a meal of cassava and/or plantain.

For boiling soup the time varies by 22 minutes. A more detailed study of the questionnaire indicates that the difference in boiling time for the soup depends on the time for pounding the fufu, which is "started when the soup is boiling".

Energy saving potential in the food preparation process in Ghana

In the following, energy losses are calculated for three-stone stoves and an improved stove. For each stove calculations are made both with a standard cooking performance and with an energy efficient cooking performance. The results are estimates based on the numbers from the literature and the results of the questionnaires. The efficiency is defined as the ratio between the heat ending up in the food being prepared and the input energy in the form of biomass. The maximum value is found in laboratory experiments with water boiling test. The efficiency at each step of the energy chain is compared to the optimal situation (relative efficiency). Finally the energy losses are cumulated.

In Table 4 we have followed the energy chain in Figure 1 with a three-stone stove, calculating the energy loss in the various parts of the process. The stove efficiency is 21% as discussed earlier. The firing control is estimated to have a relative efficiency of 80%, due to the fact that the cook does not prepare the fuel optimal, and the fire is not treated optimally during the cooking process. The relative pot efficiency is estimated as 80% as the use of pots is not optimal and the pot is not placed optimally. The relative efficiency of the cooking performance is estimated to be 50% of the optimal due to the reluctance in use of lid, the reluctance in use of optimal amount of water and the reluctance in simmering the food when boiling is not necessary. The final energy index is only 6.7.

Energy Chain	Relative efficiency %	Energy index
Biomass		100
Stove (Optimal, Water boiling test)	21	21
Firing Control	80	17
Pot	80	13
Cooking Performance	50	6.7
Resulting index for warm meal		6.7

Table 4 The energy chain and relative efficiencies with a standard cooking performance on three-stone stoves compared to optimal use with three-stone stoves (rounded numbers).

Table 5 shows the energy chain for the three-stone stoves, but now with an energy-efficient cooking performance throughout the process taking advantage of most the many saving options. Here the relative efficiency is increased to 90% for each step. The final index of 15 means a reduction of the biomass used by more than 100% compared to the standard food preparation process.

Energy Chain	Relative efficiency (in %)	Energy index
Biomass		100
Stove	21	21
Firing Control	90	19
Pot	90	17
Cooking Performance	90	15
Resulting index for warm meal		15

Table 5 The energy chain and relative efficiencies for a three-stone stove with energy efficient cooking performance (rounded numbers).

The same calculation are carried out for an improved stove as shown in Table 6 and Table 7. The improved stove is assumed too have a stove efficiency of 27%[14] which is 30% higher than for the three-stone stove. The firing control is estimated to be 90% in the standard cooking

[14] Nielsen, 1996: Efficiency tests on the pyrolysis gasifier stove PekoPe.

performance as this is basically where the stove has been improved. Pot efficiency is estimated to be 80% and cooking performance 50%. It is seen that the final energy index is 9.7. With an efficient cooking performance, where relative efficiency of 90% are used for each step the final energy index is 20.

Energy Chain	Relative efficiency (in %)	Energy index
Biomass		100
Stove	27	27
Firing Control	90	24
Pot	80	19
Cooking Performance	50	9.7
Resulting index for warm meal		9.7

Table 6 The energy chain and relative efficiencies for an improved stove with a standard cooking performance (rounded numbers).

Energy Chain	Relative efficiency (in %)	Energy index
Biomass		100
Stove	27	27
Firing Control	90	24
Pot	90	22
Cooking Performance	90	20
Resulting index for warm meal		20

Table 7 The energy chain and relative efficiencies for an improve stove with energy efficient cooking performance (rounded numbers).

In Figure 2 the results of these estimations are shown. It is seen that the three-stone stoves used in an energy efficient way are more efficient than an improved cookstove with a stove efficiency of 27% used with standard cooking performances. However, if the energy efficient cooking performance is carried out on the improved stove, the total efficiency will double, using only one third of the amount of biomass as the three-stone stove used with standard cooking performance. The difference between the use of the improved stove and the three-stone efficiently, gives a biomass saving of 25% for the whole energy chain.

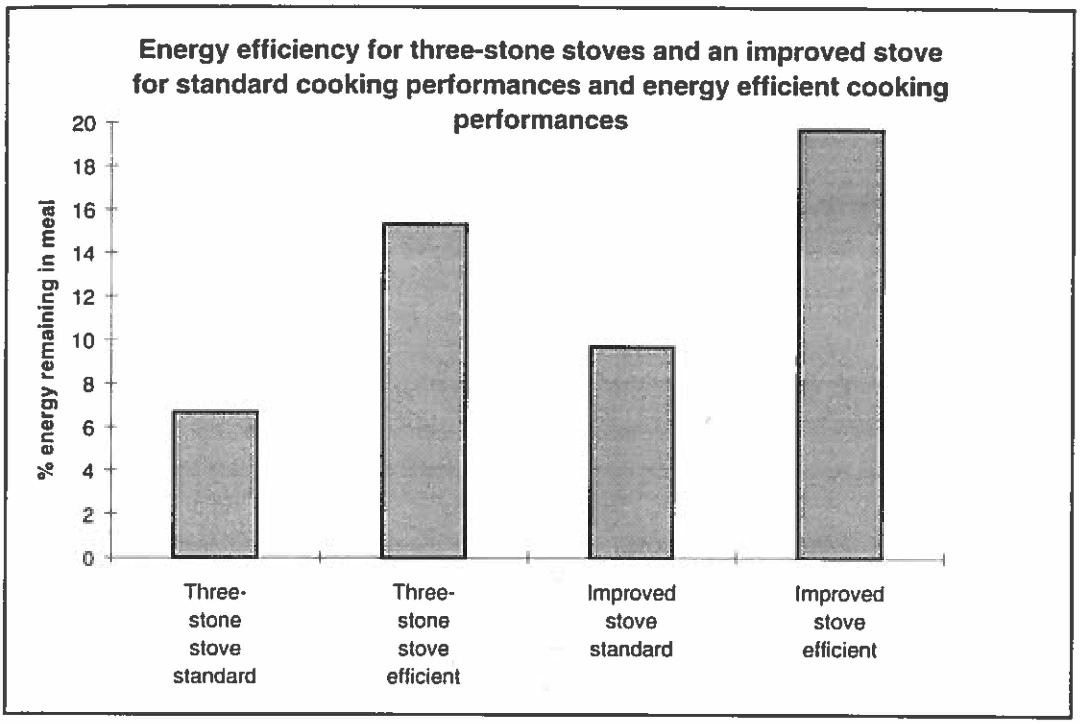

Figure 2 Energy efficiency for three -stone stoves and an improved stove in standard cooking performances and energy efficient cooking performances.

Conclusions

The fuel for cooking in Ghana is mainly biomass either in the form of wood, agricultural residues or charcoal. Cooking is the main energy consuming activity in Ghana. A questionnaire survey has been conducted including 10 households in Abodom, 100 km north-west of Accra, Ghana. An energy chain for the cooking process is established and the possible conservation options are surveyed in kitchen performance.

The energy consumption per person equivalents vary more than 100%, which is not only due to a variation in family size. The use of lid varies from cooks using the lid 100% to cooks only using it 30% of the time. The cooking time also varies for the same kind of meal. The variation in time for boiling fufu is around 50%.

The heat loss is largest while simmering after the boiling point has been reached. Most cooks tend to continue the high heat supply even though it is not necessary. This process is often carried out without lid on the pot even though the use of lid will reduce the energy loss considerably.

The average fuel consumption for preparing the daily meals is measured to be 2.1 tonnes/household/year. This is only is 20% higher than the per family fuelwood consumption in the northern part of Ghana (Guinea Savanna) where fuelwood is scarce. The is surprising and indicates that the figure for the national woodfuel consumption for cooking in Ghana is highly overestimated. As mentioned before the average fuelwood consumption should be around 5 tonnes per household for Ghana if the official figures for biomass consumption are used. If the figure for the total biomass consumption in Ghana is correct, the predominant consumer of biomass is not the households, but probably the industry. The biomass consumption for food processing is probably highly underestimated. What makes its quantification difficult, is that a considerable part of the food processing is probably performed in the households.

The energy consumption for the food preparation has been measured and energy saving options have been determined for some parts of the energy chain. The results together with numbers from the literature show that the possible options for energy conservation through the entire energy chain of the present technology are higher than just switching to a more efficient biomass stove. The savings are 25% for just changing the stove and the savings for changing cooking habits are more than 100% using present technology. When the efficient cooking performance with an improved stove is compared to the standard cooking performance at three-stone stoves the energy consumption is reduced to one-third.

Obtaining the efficient cooking performance is therefore, considerably more important than using an efficient stove. It is, however, easier to address the stove than to change the cooking habits of the cook. The focus on the stove is also convenient " as the conclusion often is that "people do not want to use the improved stove" and then nothing is done. The focus on the energy chain as a whole, and the cooking performance in particular, indicates that training and education of the cook is necessary to solve the fuelwood problem.

References

Baya-Vuma, A. 1989
10 Years of Improved Stoves in the Sahel. LCHS, Lund University Publications No 27.

Dewees P. A. 1989
The Woodfuel Crisis Reconsidered: Observation on the Dynamics of Abundance and Scarcity. World Development, Vol 17, No 8, pp 1159-1172.

Gitonga, S. Muchiri, L., and Owen, M. 1994
Back to basics in the Kitchen. Boiling Point, No 32, pp. 3-5.

Hagan, E. B. and Addo, S. T. 1994
Determination of Domestic Energy consumption patterns and their impact on the environment in Ghana. African Development Bank, First Draft.

Khummongkol, P. 1986
Review of Standard Methods of Testing Stoves Efficiency. In Proceedings from ASEAN Conference on Energy from Biomass, pp 118-130.

Ministry of Energy, Ghana, 1991:
A Report on Energy Use Patterns in Bolgatanga, Bawku East and Bawku West Districts of the Upper East Region of Northern Ghana. Ministry of Energy, Ghana, Accra.